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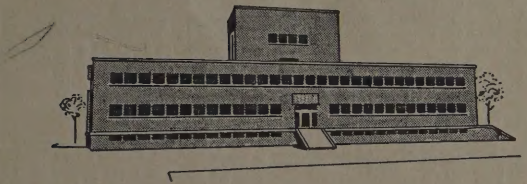

GURO GJELLESTAD and HELGE DALSEIDE

ON SOLAR IMPOSED SMALL DAYLIGHT FLUCTUATIONS IN THE GEOMAGNETIC FIELD ✓

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ON SOLAR IMPOSED SMALL DAYLIGHT FLUCTUATIONS IN THE GEOMAGNETIC FIELD

BY GURO GJELLESTAD AND HELGE DALSEIDE
Geophysical Institute, University of Bergen.

Abstract: A study of monthly means of the three-hour range geomagnetic character-numbers, *K*-indices, shows that small fluctuations, characterized by day-time/summer maxima (called *J* after Mayaud), are present at five observatories, representing approximately a meridian section from a point just inside the auroral zone (geomagn. lat. 71°) through this zone (Tromsö) to geomagnetic latitude 58°. It is suggested that *J* is probably a global effect, intimately connected with the sun. The sun's contribution is a more or less purely geometrical effect, increasing with the sun's declination. Not only is *J* superimposed on the solar quiet daily variation, but it appears to be superimposed on the general geomagnetic activity connected with the solar activity. Another effect with night-time/equinoxial maxima (called *N*) is also present. *J* and *N* must have very different physical causes. It is suggested that *J* appears as a statistically mean effect on the geomagnetic field of the mean solar wind. *J* is a relatively small effect, which may be masked by stronger effects if absolute values are studied. The semilogarithmic scale of the *K*-index has proved convenient for studies of this small effect.

1. Introduction. The present paper is a preliminary exploration of a problem which may have bearing on the sun's short-wave electromagnetic radiation or on the solar wind corpuscular radiation.

Mayaud (1955, 1956) found at high geomagnetic latitudes two main types of apparently irregular magnetic acticity (agitation), one having its maximum near local noon in summer (called *J*), and one having maxima at night and at the equinoxes (called *N*). In Thule, at the geomagnetic axis point, only the *J*-effect was present. In Sodankylä and Niemegh the *J*-effect was hardly distinguishable, and Mayaud doubted if it was present at all in Sodankylä. Lassen (1958) confirmed Mayaud's result for Godhavn.

Nicholson and Wulf in a series of papers (1955, 1958, 1961 a, b, 1962) studied the *J*- and *N*-effect for observatories at geographic latitudes — 30.5° and between + 18.5° and 36° (at various geographic longitudes) and found that the *J*-effect was present in the 10 most quiet days of each month. A corresponding result had earlier been obtained by Narayanaswami (1941), for Bombay at geographic latitude + 18.5°. Afternoon and morning maxima have also been found [see references in a paper by Hope (1961)], but they have no bearing on the problem to be discussed here.

2. Formulation of the problem. The fact that Mayaud «lost» the *J*-effect when leaving the northern polar cap, while Nicholson and Wulf as well as Narayanaswami detected it at low latitudes, has intrigued us. We therefore decided to study the development of the *J*-effect from an observatory just inside the auroral zone (Bear Island), through this zone (Tromsö, and possibly Sodankylä) and southwards. We stopped at Lovö because the next observatory studied, Wingst, at a latitude comparable to Niemegh, showed a behaviour that may represent a transition zone, and therefore deserves a more careful study. In the present study advantage has been taken of the long series of *K*-indices of the Dombås observatory, going back to 1925, in particular for studies of the long-term variations of *J* and *N*.

In the present paper the studies have been concentrated on five Scandinavian observatories. In Table I are listed the observatories, their geographic and geomagnetic coordinates, and for each of them the maximum period of data used. The investigation is based on the three-hour range geomagnetic characternumbers, *K*-indices. In the following the symbols *K1*,*K2*,*K3* ..., *K8* will be used, *K1* being the *K*-index for the first three-hour interval in the Greenwich day. The time scale is not essential at the present stage of investigation, as the longitude differences of the five observatories are not large. The GMT time scale is used for *K*-indices, as defined above.

Table I

Observatory		Geographic		Geomagnetic		Series
		lat	long	lat	long	
Bear Island	B4	74°30′	19°00′	71.0°	123.0°	1951–60
Tromsö	*TR*	69 40	18 57	67.1	116.7	1951–60
Sodankylä	*SO*	67 22	26 39	63.8	120.0	1953–62
Dombås	*DO*	62 04	9 07	62.3	100.1	1925–61
Lovö	*LO*	59 21	17 50	58.1	105.8	1943–58

The manual computations have made it necessary to choose material available in a form convenient for such treatment. We do believe, however, in spite of the inhomogeneity of the data, that they are representative, in as far as we have taken care to include for each observatory at least one (11-year) solar cycle (exception is Sodankylä, where one year is missing). The investigation will be followed up by studying more complete data with the help of an electronic computor. A more comprehensive paper will then be published.

3. The daily variation of *K*-indices (*J*, *N*). In Figure 1 are presented the daily variations in the *K*-indices for summer and winter as means of several years for the five observatories in Table I. Lloyd's seasons are not used here, only June/July and January/December, in order to bring out more clearly the contrast (for Sodankylä only one summer and one winter month).

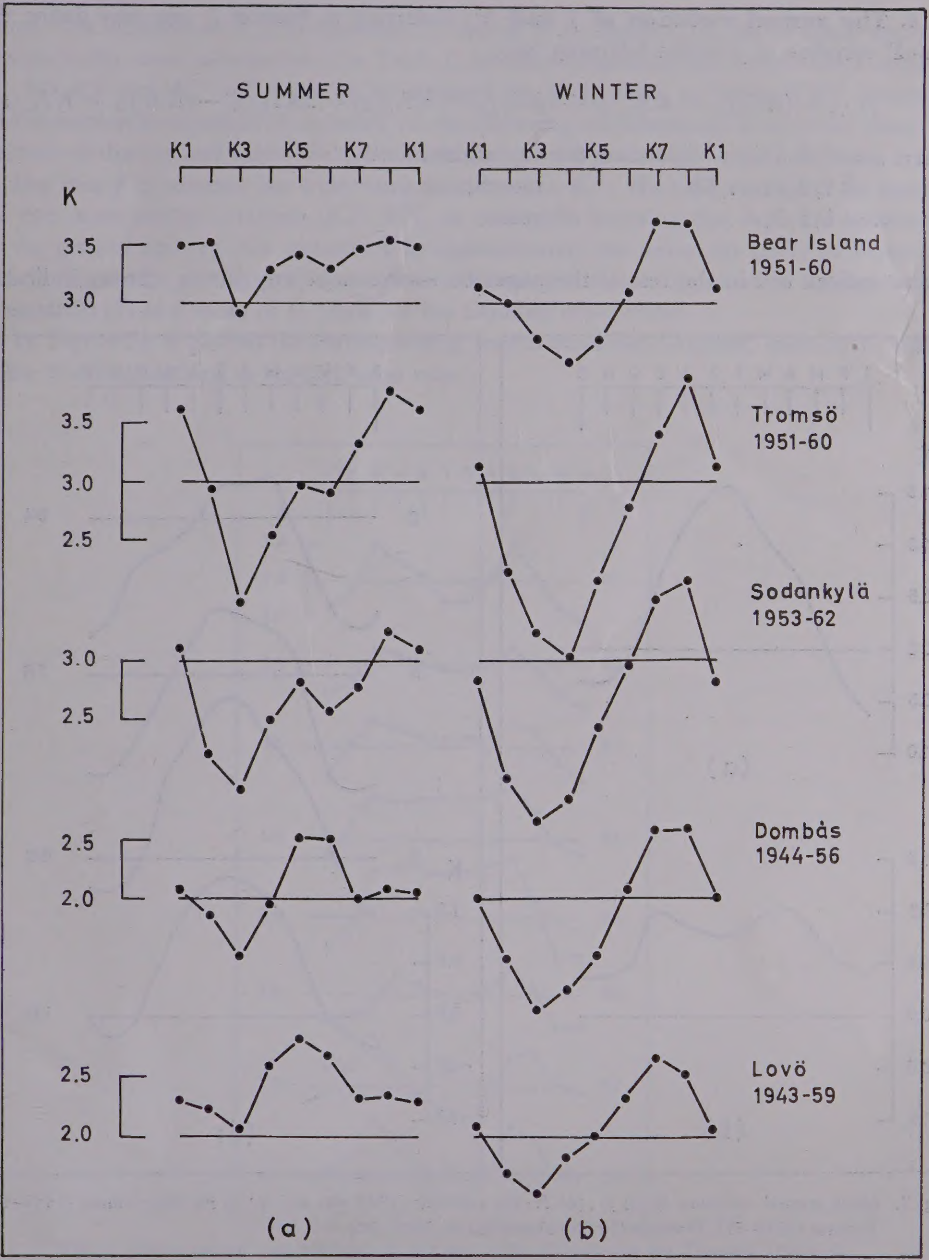

Fig. 1. Mean daily variations in K-indices for summer (a), winter (b) for five observatories.

4. The annual variation of J and N. Referring to Section 2, one may define the annual variation of J in the following way,

$$J_{i,j,k} = (K5_{i,j,k} - K3_{i,j,k}) + (K5_{i,j,k} - K7_{i,j,k}) = 2K5_{i,j,k} - (K3_{i,j,k} + K7_{i,j,k}), \tag{1}$$

where $i = 1,2,3,\ldots$ indicates the day of the month,
$j = 1,2,3,\ldots,12$ » » month,
$k = 1,2,3,\ldots$ » » year.

These indices will in the rest of the paper be used consistently in the manner indicated

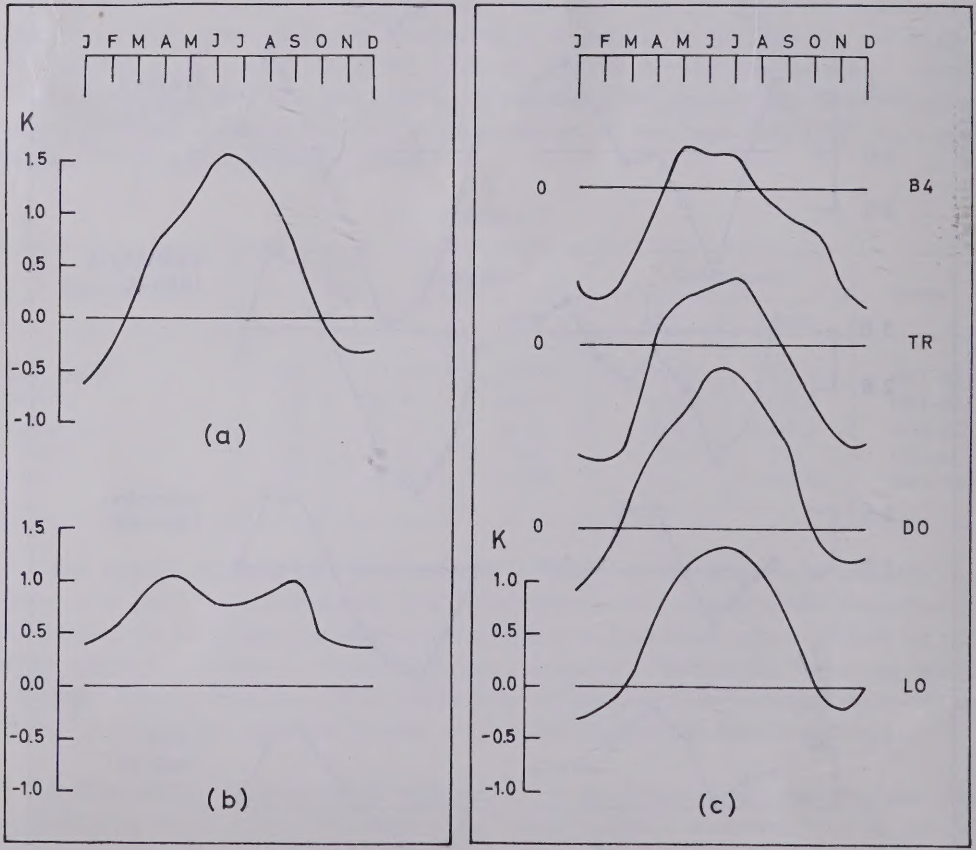

Fig. 2. Mean annual variation of (a) J_j, (b) N_j for Dombås (1925–61) and (c) J_j for Bear Island (1953–57), Tromsö (1952–57), Dombås (1925–61) and Lovö (1943–58).

above. The definitions of *J* in equation (1) and of *N* in equation (2) below apply approximately to the observatories listed in Table I. At other longitudes the Greenwich *K*-indices *K1*,*K3*,*K*5 and *K7* will have to be replaced by *K*-numbers in other *GMT* intervals. The definition in equation (1) is based on the following consideration: Due to the complex mixture of the day and night effects, it is not known if *J* has a night-time minimum, but it is clear that *J* in summer has a day-time maximum in *K5* . We have measured *K5* against the two most neutral intervals (*K3* , *K7*), on each side, knowing that both are influenced by the general activity, but apparently in approximately the same way (refer to Figures 1 and 3). Figure 2a gives (twice) the annual variation of the monthly mean of the expression in equation (1) as a mean of 37 years for the Dombås observatory.

In Figure 2b is plotted the corresponding annual variation (Dombås, mean of 37 years) of the *N*-effect, defined in the following way,

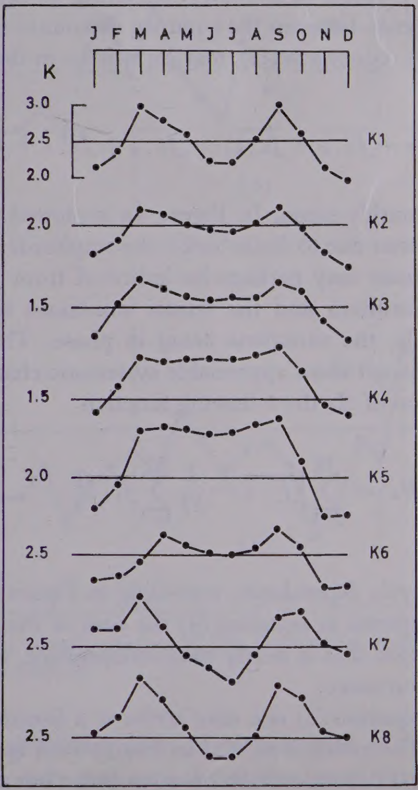

Fig. 3. Mean annual variations of *K* for the eight *K*-intervals for Dombås (1943–58).

$$N_{i,j,k} = (K1_{i,j,k} - K3_{i,j,k}) + (K1_{i,j,k} - K7_{i,j,k}) = 2K1_{i,j,k} - (K3_{i,j,k} + K7_{i,j,k}), \tag{2}$$

the definition of N being equivalent to the definition of J ($K5$ substituted by $K1$).

The curves for Bear Island, Tromsö and Lovö in Figure 2c, obtained in the same way as for Dombås, clearly demonstrate that the J-effect has the same type of annual variation at the four observatories, with decreasing amplitude from summer through the equinoxes towards winter.

For comparison the annual variation of the 8 K-indices of a Greenwich day is presented in Figure 3. It appears that the K-indices, $K1, K2, K3, \ldots, K8$, separately have an annual variation that has more or less equinoxial maxima (Dombås, means of 10 years). Figure 3 is similar to Figure 5 in the paper referred to by Narayanaswami.

5. Long-term variations of J and N. In this section are presented some results of 37 years of K-indices for Dombås observatory. Referring to equation (1), the amplitude variation of J, *i.e.* the difference between the summer maximum and the winter minimum (Lloyd's seasons this time, to reduce scatter), may be written in the following way,

$$A_k = (\overline{J_{5,k}} + \overline{J_{6,k}} + \overline{J_{7,k}} + \overline{J_{8,k}}) - (\overline{J_{1,k}} + \overline{J_{2,k}} + \overline{J_{11,k}} + \overline{J_{12,k}}), \tag{3}$$

where the bar indicates a monthly mean. In Figure 4a is plotted the amplitude variation. It appears that apart from scatter due to disturbance, the amplitude is nearly constant during these 37 years; a slight increase may perhaps be indicated from 1925 to 1961. It can be shown that the summer maximum and the winter minimum separately show a slight variation with the solar cycle, the variations being in phase. This is in agreement with the result above, that A_k does not show appreciable systematic change with time.

In contrast to the variation of A_k the following function

$$B_k = \sum_{j=1}^{12} \left[\overline{J_{j,k}} - \frac{1}{37} \sum_{k=1}^{37} \overline{J_{j,k}} \right], \tag{4}$$

shows a clear 11-year solar cycle dependence, according to Figure 4b.

Substituting in the parenthesis in equation (4) the sum of the numerical values of the two terms, we obtain a function that is nearly time-independent, as A_k from equation (3), apart from scatter due to disturbance.

Using the definition in equation (2) one may arrive at a function for the N-effect corresponding to equation (4). The result is plotted in Figure 4c. Figures 4b and c show that the J- and N-effect have a clear dependence on the solar cycle, but apparently with different phase.

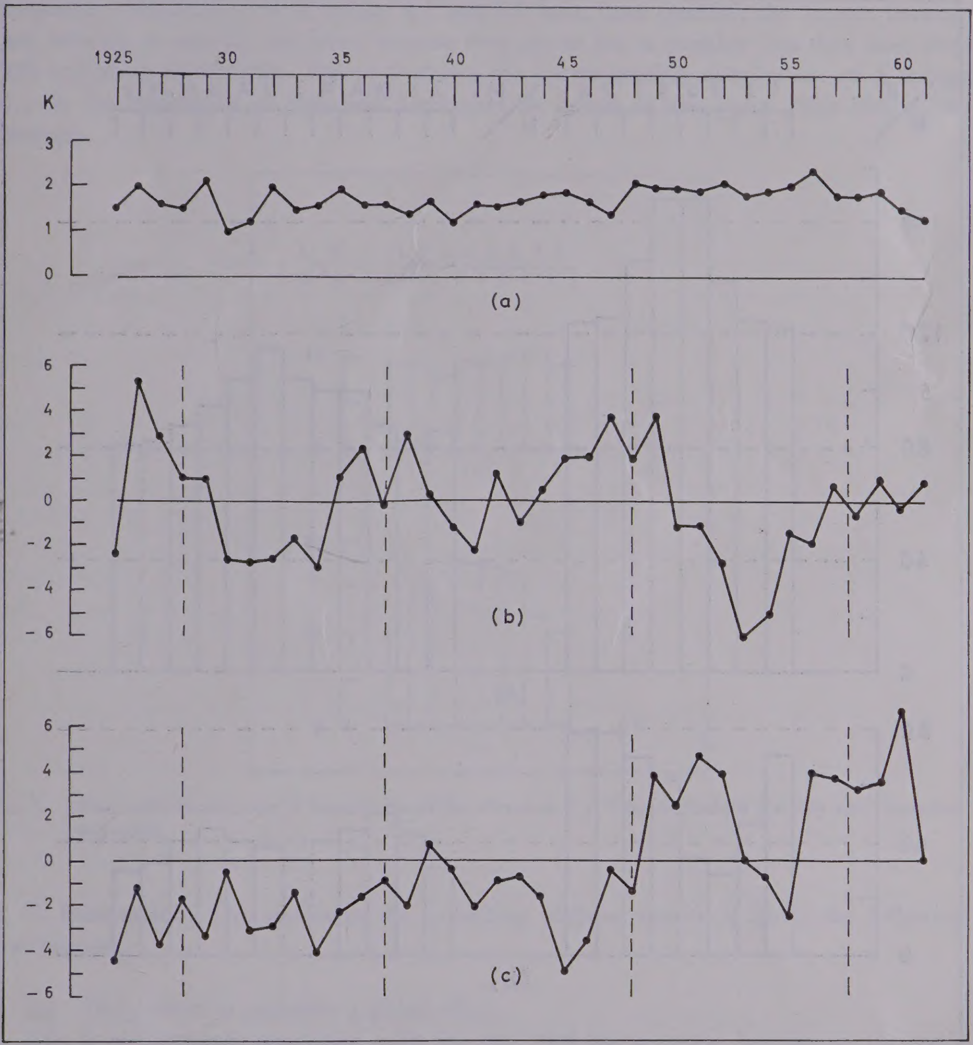

Fig. 4. The amplitude of the annual variation of J(a), the function B_k(b) and the corresponding function for N(c) for Dombås 1925–61.

6. Daily and annual distribution of frequencies of *K*-numbers. In Figure 5 are given histograms of the daily and annual distribution of the frequencies of the *K*-values (2 + 3), (4 + 5) and (6 + 7), respectively, for Dombås observatory, as means of 11 years.

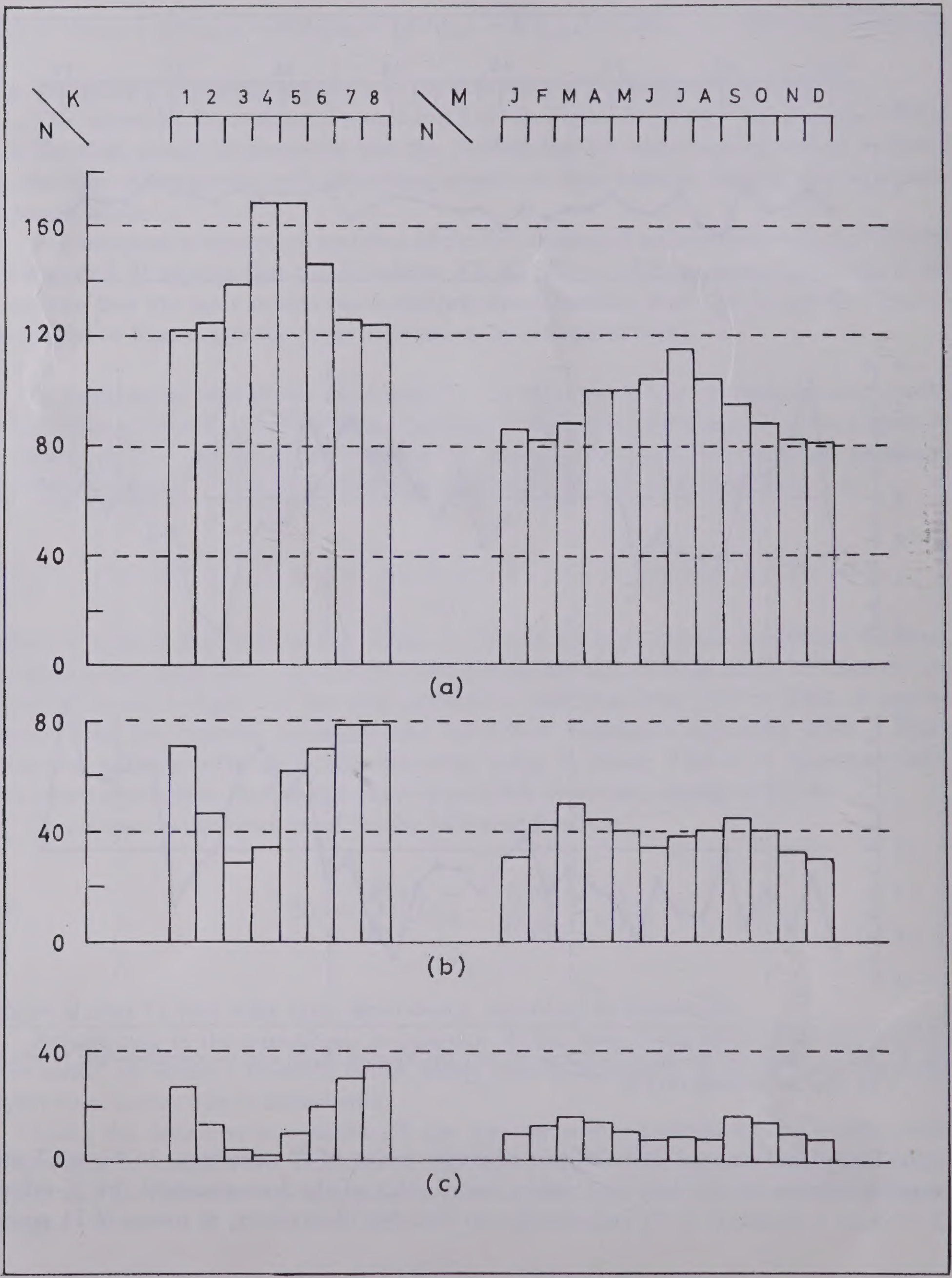

Fig. 5. Mean daily and annual distribution of frequencies of the *K*-values 2 + 3 (a), 4 + 5 (b) and 6 + 7 (c) for Dombås 1952–62.

Frequency distributions of K-values 0.1 and 8.9 have been omitted, the former because they indicate no activity, the latter because they are so few in number that they have very little statistical significance. Figure 6 shows the corresponding distribution of K-values $(2 + 3)$ for Sodankylä in July and December as means of the years 1953–1963 (1961 missing).

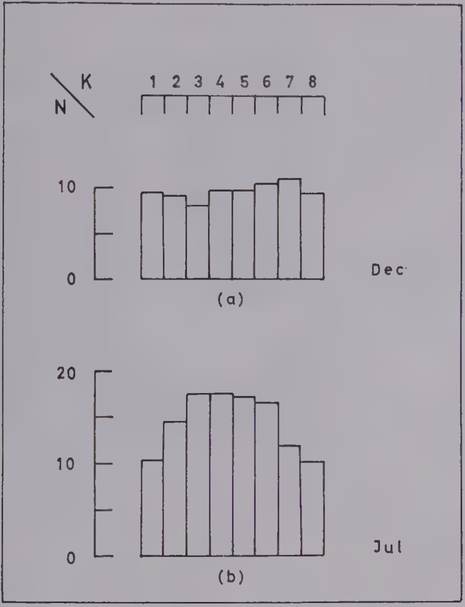

Fig. 6. Mean daily distribution of frequencies of the K-values $2 + 3$ for Sodankylä for July and December 1953–1963.

7. Discussion. The results in the preceding sections appear to invite the following conclusions:

(a): The J-effect is probably a global effect.
(b): It is intimately connected with the sun, and has a strong bearing on the sun's declination.
(c): J and N have different physical causes.
(d): J is not only as N superimposed on the solar quiet daily variation, but appears to be superimposed on the general geomagnetic activity connected with solar activity.
(e): J may be the effect on the geomagnetic field caused either by fluctuations in the

normal short-wave (UV and X-ray) radiation from the sun, and/or by the mean solar wind.

(f): *J* is a small effect, which may be masked by stronger effects if absolute values are studied. The semi-logarithmic scale of the *K*-index has proved to be convenient for studies of this kind.

(a): Figure 1a shows that the *J*-effect is present in all five observatories in summer, the *N*-effect also in winter.

According to Figures 5a and 6b the smaller *K*-values show a tendency to be dominating in day-time in Dombås and Sodankylä, for the latter shown only in July. Figures 1b and 6a may indicate that the *J*-effect does not exist in winter at the latitudes of the observatories in Table I. It is, however, more likely that the effect may be present, but is too small to be detected.

For the most southernly observatories, Dombås and Lovö, the *J*-effect is dominating in summer, while at the other observatories the *N*-effect is dominating in winter as well as in summer.

We have in this paper been able to trace the *J*-effect from Bear Island, just inside the auroral zone, through this zone, to Lovö at the geomagnetic latitude of 58°. On the other hand, Nicholson and Wulf showed that the *J*-effect was present at — 30.5° and between + 18.5° to + 36°, while Mayaud proved its existence at stations inside the auroral zone (confirmed by Lassen for Godhavn). The quoted results of Mayaud, Nicholson and Wulf, and the results given in this paper, combined with the deductions in points (b) and (f), tempt us to suggest that the *J*-effect is a global phenomenon, intimately connected with the sun.

(b): The daily noon maximum and the annual variation of *J*, shown in Figures 1a and 2c for four observatories, clearly indicate a dependence on the sun's declination. Lassen came to the same conclusion for Godhavn. It follows from Figure 5b that the annual distribution of the frequencies of the small *K*-values for Dombås follows the same pattern as the annual variation in *J* (Fig. 2c). That would be expected if the small *K*-values are indicative of the *J*-effect. Figures 6a, b may be interpreted in the same way. In Section 5 is pointed out that the summer maximum and the winter minimum of *J* both vary with the solar cycle, and in phase, but the difference shows no appreciable systematic change during 37 years (Dombås). The only possible conclusion to be drawn from the annual variation of *J* and the constancy of the amplitude A_k [eq. (3)] is that the contribution from the sun to the geomagnetic field perturbation, here called *J*, must, apart from scatter, be a more or less purely geometrical phenomenon, the effect increasing with the sun's declination.

(c): In contrast to the annual variation of the *J*-effect just discussed, the *N*-effect shows the familiar annual variation of the general geomagnetic activity due to solar activity, namely with equinoxial maxima (Fig. 2b) for Dombås (refer also to Mayaud). From Figure 5 it follows that for Dombås the larger K-values are indicative of the N-effect and they show the same annual variation as does N (Fig. 2b). Comparing the annual variations of J and N one may conclude that they must have very different physical causes. This has been suggested, on the same grounds, by other workers. It is believed, however, that the way of presenting the problem in this paper has brought this point out more instructively and definitely. Moreover, a numerical measure has been found for the annual variation (in terms of K-indices).

It appears from Figures 4b, c that J and N have a clear dependence on the solar cycle, but the maximum of the J-effect coincides with sunspot maximum, while N has its maximum during the descending phase of the sunspot numbers, as have the recurrent storms and the M-regions. This result represents an important independent proof of the different physical causes of J and N, and has to our knowledge not been shown before.

(d): Figure 3 shows that at Dombås all K-intervals have the characteristics of the general magnetic activity connected with solar activity, namely equinoxial maxima. Figure 2a, on the other hand, shows that $K5$, the mid-day K-index, relative to $K3$ and $K7$, has a summer maximum. This may be interpreted in the way that J is superimposed on the general activity for which N, according to its character, may be representative. According to the definition of the K-indices both J and N are, of course, superimposed on the solar quiet daily variation. The constancy of A_k and the in-phase independent variations of the summer maximum and winter minimum with the solar cycle discussed in (b), support the deduction that J must be an effect superimposed on the general geomagnetic activity connected with solar activity.

(e): The behaviour of the N-effect, as pointed out in (c), is in agreement with experience at the latitudes considered of geomagnetic disturbances connected with solar activity. Considering that the K-index has been introduced as an indicator of corpuscular radiation from the sun, the behaviour of the J-effect, on the other hand, characterized by day-time/summer maxima, appears somewhat puzzling. It is well known that the solar quiet variation has a corresponding diurnal and annual variation (Chapman and Bartels, 1940), and also varies with the solar activity. Some workers have, therefore, suggested that the J-effect might be a residual part of Sq, that has not been removed. Drawing the «normal line» (see, for instance, Gjellestad and Dalseide, 1963) is admittedly subject to some personal judgement. This explanation can be ruled out because it would mean that at the five observatories here considered, over at least 10 years (Dombås 37 years), the «errors» would increase systematically towards mid-day and towards summer. The second explanation to be considered is that the «normal line» is not a smooth curve, as is usually assumed, but varies with fluctuations in the solar UV and X-ray radiation. The day-time/summer maxima of the J-effect point in favour of this explanation, as does the result shown in Figure 4b (discussed in (c)), but it still remains to explain the puzzling constancy of A_k. An objection to this explanation is that at the observatories considered the (geomagnetic) solar flare effect, *sfe*, due to enhanced solar UV and X-ray radiation, is usually not observable. This has suggested a third possible explanation, namely that the *J*-effect, defined here as a statistical mean, is the solar wind mean effect on the geomagnetic field. A preliminary inspection of selected magnetograms from Dombås observatory gives an indication that on quiet and nearly quiet days, the day-time disturbances very often have the character of small perturbations, reflecting perhaps solar wind corpuscular perturbations of the geomagnetic field at large distances.

(f): From Figures 5a and 6b it appears to be clear that at Dombås (means of 11 years) and at Sodankylä (means for July and for December for 10 years) the major contribution to the *J*-effect are the *K*-values 2 and 3 (mean 25–35γ). The fact that the smaller *K*-values at certain hours of the day have a much higher frequency than the larger but less frequent *K*-values, make the former more significant in a statistical mean during those hours. This probably is the reason why it has been possible not only to prove the existence of the *J*-effect at Sodankylä, but even in the strongly perturbed auroral zone. One will now understand why Mayaud could not find conclusive signs of the *J*-effect in Sodankylä. He used *K*-indices, but converted into absolute values, and the numerically small *J*-effect was obscured by the numerically stronger *N*-effect. It is interesting to note that while the *K*-indices in some cases may appear unsuitable for statistical work because of their semi-logarithmic scale, when looking for effects of the kind studied here, the semi-logarithmic scale has proved to be an advantage because one may discover small effects, that might otherwise be obscured by numerically stronger effects. At other latitudes than Dombås' and Sodankylä's, larger *K*-values then 2, 3 may be responsible for the *J*-effect, for instance inside the polar zones where the daytime variations are numerically stronger, or at lower latitudes due to the contraction of the *K*-scale. The objection raised by Fel'dshtein (see Hope 1961) that the *K*-indices are unsuitable because of the non-linearity of their scale does not apply to the present study of the *J*-effect, because the scale for the smaller *K* -values is quasilinear.

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